The History of Flight Software
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Road Map

- Early Missile Guidance computers.
- Computers move onboard launch vehicle.
- Early Manned missions.
- Earth-orbiting spacecraft OBC’s
  - OBP/AOP
  - NCCC-1
  - DOC
- Care and Feeding.
- More to do.

What’s not included

- Planetary missions.
- Russian, French, and other foreign efforts.
- Avionics, Aircraft, balloon systems.
- Salyut, Skylab, Space Station Freedom.

14th century missile guidance

- 火龍經, (***Fire Dragon Manual***), Jiao Yu and Liu Ji, Ming Dynasty
- Synopsis: “Launch whole bunches of these, and see if we hit something.”
- Advantage: No software required.
- Things have gone downhill since then.

1940's Missile Guidance

- Pre-calculations. Launch from a known position in a known direction.
- Known distance => determines burn time.

- German V-2 Field Operations Manual

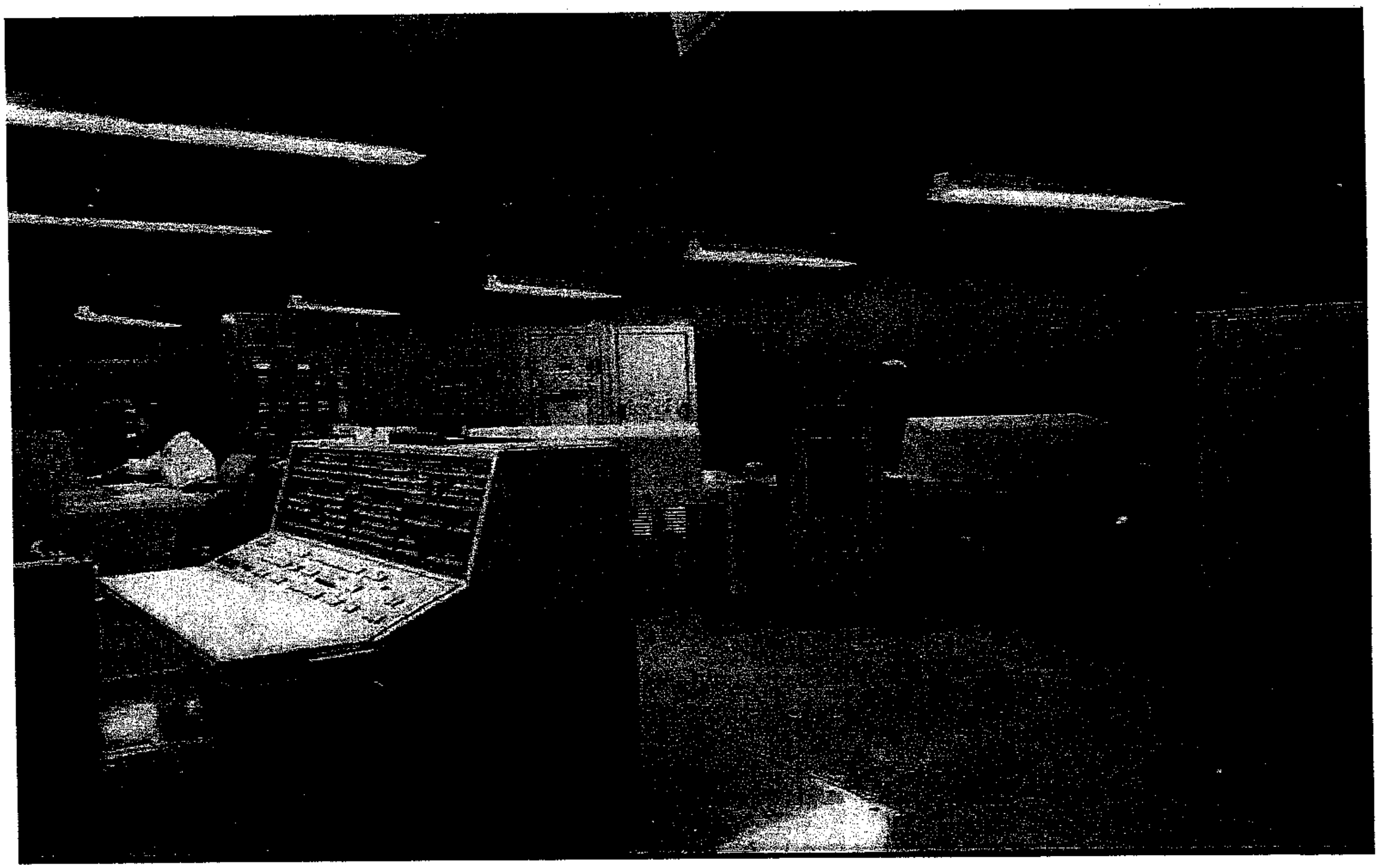
  (assumes high school education)

  "...point fin number 1 towards London..."

1960’s missile guidance computers

- Univac *Athena* computer for the Titan missile system
- Burroughs *Mod 1* for the Atlas System
  (Smithsonian has 1 of each)
- Not for flight – exceeds weight budget by 9 tons.
- Requires 370 square feet of floor space underground in hardened bunker.
- Using radar data input, calculate course corrections during burn.
- Only has to work for a couple of minutes.
- Programmed in assembly; Harvard architecture

Univac Athena



Athena

- Sperry Rand Univac; 1957; Seymour Cray was chief designer.
- Harvard architecture; 256 words of 24-bit core memory for data and 8192-word drum for program and constants.
- BattleShort: In this mode, referred to as “melt-before-fail”, the power to the machine could NOT be shut off.
- The last launch supported by an Athena computer was a Thor-Agena missile launched in 1972 from Vandenberg AFB in California. The Athena was used on over 400 missile flights.

Onboard Missile guidance computers

- Driven by need to launch from submarines.
- Saturn V – launch vehicle sequencing was done by mag tape.

Gemini Guidance computer

- Mercury manned spacecraft did not have an onboard computer. First digital computer on a manned spacecraft was on Gemini.
- Gemini, designed for rendezvous, had a computer that could actually take over from the Titan launch vehicle computer.
- 59 pounds, 140 millisecond ADD time, IBM.
- 16 machine language instructions. Equations verified at the Fortran level.
- Auxiliary tape memory (VIII and later) and glass delay line registers.

Apollo Computers

- MIT Instrumentation Lab, using heritage from Polaris missile guidance computer.
- Eventually, required 5,000 gates.
- 60% of the total US production of microcircuits were used in Apollo.
- 11.7 microsecond cycle time.
- Software released Jan. 1966, first flight August 1966.
- No in-flight errors attributed to software.
- 2,000 person-years independent verification.

Apollo Guidance computer

- One in command module; one in lunar lander.
- 152 kbytes of storage, mission total.
- 6 inches, x 1 foot x 2 feet; 70 lbs, 55 watts.
- 5600 3-input nor gates.
- Cycle time 11.7 uSec.
- YUL – assembly language of 40 ops, and Interpretive language for math-intensive calculations
- Calculations internally in metric, but astronauts preferred English units for display.

  (what's the worst that could happen?)

Onboard Spacecraft computers

- Drivers
  - Autonomy – no longer rely on stored commands.
  - Flexibility of operations.
  - Responsive to unanticipated events.
- Requirements
  - Support system, assembler, linker/loader, debug facility.

NASA Earth orbit Missions
- some examples

- OAO’s OBP
- GSFC’s NSSC-1
- ATS-6’s DOC

NASA's OBP

- On Board Processor for the Orbiting Astronomical Observatory (OAO) Mission *Copernicus* (Grumman Aerospace) 1972.
- Experimental (not required for operations)
- After 4 ½ years on-orbit, suffered an ALU hardware problem. (Bit 6 of adder stuck)
- Diagnosed from the ground to the chip level.
- Onboard software re-written to bypass the problem. (ie, don't use bit 6)

Early Support systems

- Large mainframes.
- Source on punched cards and mag tape.
- Assembly language (if not machine language)
- Dedicated hardware simulators ($$$)
- Custom interfaces ($$$)

AOP

- Next model was the Advanced On Board Processor (AOP), flown on Landsat B and C, IUE, OSS-1 (payload on STS-3).
- AOP cycle time for IUE mission was 1.3 microseconds; mission had 12k of 18 bit words.

IUE's AOP woes

- Temperature spec was 38 deg C, post-launch environment was 52 to 55 deg C
- Many OBP crashes, leading to loss of attitude control. Nothing like this had ever happened in test.
- Dump analysis showed corrupted interrupt vectors.
- Personnel who developed the software had been reassigned to other projects.
- No ground-based facility that could duplicated the OBC temperature seen in flight.
- Protection against "hits" was completed 2 months post-launch. (work-around)

IUE, continued

- 1.5 years after launch, detailed study of cause.
- Analysis revealed a fault condition after an ADD of two values, both close to zero, both negative.
- Interrupt causes context switch. When the adder circuit was hot, it took longer to settle.
- The adder was also used to generate the target address. (no separate program counter adder)
- Sometimes, with previous negative numbers, bit 15 was not cleared => wrong target vector!
- Diagnostic patch uploaded Jan. 1980.

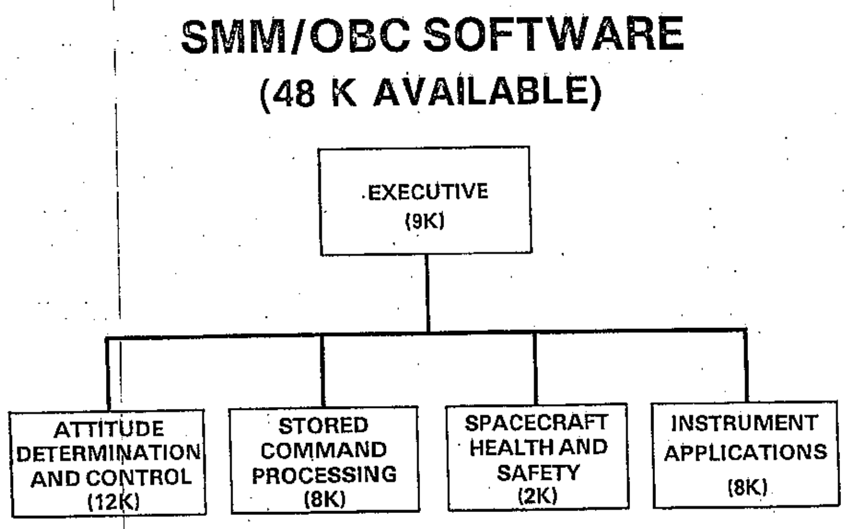
NASA Standard Spacecraft Computer

- Developed as a standard component for the MultiMission Modular Spacecraft (GSFC) 1974.
- 18 bits, core or plated wire memory; up to 64 k.
- used on the SMM, Space Telescope, and Landsat-D Missions, among others.
- Westinghouse and GSFC.
- DTL logic – lowest power parts available on the Preferred Parts List; 1700 SSI packages.
- Reduced to 69 MSI chips.
- Fixed point design.

NSSC-1 programming and support

- Assembler/loader/simulator.
- Hosted on Xerox XDS 930 (24 bit)
- Simulator ran at 1/1000 real time.
- Interfaced to a breadboard OBP in a rack.
- Software Development and Validation Facility (SDVF) – added flight dynamics simulator (PDP-11/70).
- Later, HAL-S compiler by Intermetrics.

SMM software memory usage



SMM/OBC SOFTWARE
(48 K AVAILABLE)

EXECUTIVE (9K)

- ATTITUDE DETERMINATION AND CONTROL (12K)
- STORED COMMAND PROCESSING (8K)
- SPACECRAFT HEALTH AND SAFETY (2K)
- INSTRUMENT APPLICATIONS (8K)

Figure 3

NSSC-1 Flight Executive

- Executive, time slice at 25 mS.
- Stored command processor.
  - Absolute time commands
  - Relative time commands
- Status buffer.
- Required a lot of memory.

ATS-6 - DOC

- Application Technology Satellite – 6 (TDRSS pathfinder)
- Digital Operations Controller (2 units) Honeywell.
- There was to be no change in the Flight Software post launch, thus no provisions for software debug, development, and test.
- That lasted 1 sidereal day (23 h 56 m) after launch.
- Software overflow condition discovered post-launch affected the sign of the roll control loop. Worked out machine language patch literally on back of an envelope.
- Later, loss of a star sensor was countered by reprogramming to use simultaneous observations from two other orthogonal sensors.

Further work

- There are many, many more Flight Software stories and lessons-learned from orbit, the surface of other planets, from the Astronaut-users, and from other nations.
- Maybe we should pull all this information together into one place….

And, in conclusion

- “Man is the best computer we can put aboard a spacecraft... and the only one that can be mass-produced with unskilled labor.”

Dr. Wernher von Braun